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(54) Equaliser for radio receiver.

(57) A GMSK radio receiver for operation in ›resence of strong multipath interference, comprising a baseband frequency converter which operates :o produce I and Q baseband GMSK signals, which will be distorted by any multipath interference present are correlated with a plurality of different possible signals to afford in respect of each correlation a proba ignal, the probability signals being processed to determine the significance of the signal received, whereb\ 'ansmitted data is determined in the presence of multipath interference.

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IMPROVEMENTS IN O ATING TO EQUALISERS

This invention relates to equalisers for radi vers of the kind destined for operation in the presence of strong multipath interference.

Mobile telephones, for example, include sceiver of which the receiver receives transmission signals from a base station via a multitude of paths. The transmission signals are usually frequency modulated signals and the carrier frequency is The multipath interference can produce signal paths of length equal to a delay equivalent to up to fo of original data used to modulate the carrier wave. In particular, digital data or voice communications sphere are frequently of the Gaussian Minimum Shift Keying (GMSK) type. The receiver includes seband frequency converter which demodulates the received transmissions to provide I and Q ba GMSK signals distorted by the multipath inteference present.

The data to be transmitted is arranged kets and each packet is transmitted with a header including an address and a predetermined dat ence. This predetermined data sequence is employed in estimating the "channel impulse response" (nal distortion due to the multi-path interference).

If the channel impulse is determined, sub t transmitted data bits, depending on the preceeding bits can be interpreted on a probability basis.

It is possible using a Viterbi algorithm to e the received GMSK signals with all possible signals and to select, on the basis of probability, the m ely signal. This most likely signal is assumed to be the original signal.

An apparatus to effect a complete comp employing the Viterbi algorithm, would be complex, expensive, and of size and power requiremen that it would not constitute a commerical solution of the problem of multipath interference; particula ceivers such as those used in mobile telephones.

It is an object of the present invention to p an equaliser for a radio receiver wherein the aforesaid disadvantages are overcome.

According to the present invention, there vided an equaliser, for a radio receiver, comprising a converter for producing, from a received sig gital samples at baseband, means for producing an estimate of channel distortion in the receive l, a store in which are stored signal sets, means for applying the distortion estimate to the stored s ets, metric generating means for generating metrics of selected modulated signal sets with the digi nples and a processor for processing the generated metrics in accordance with a Viterbi algorithm t rmine the most probable value of the received signal.

The invention will be described further, y of example, with reference to the accompanying drawings, in which:-

Figure 1 is a block schematic diagram of a receiver including an equaliser according to the present invention;

Figure 2 is a block schematic diagram o ric generator forming part of the equaliser of Figure 1;

Figure 3 is a block schematic diagram o ric calculator of the metric generator of Figure 2;

Figure 4 is a block schematic diagram o al selector of the metric generator of Figure 2; and

Figure 5 is an 8-state trellis diagram.

In the example hereinafter described, it is ed that voice or data signals are transmitted in packets by a known system using Gaussian Minimum eying (GMSK). In such a system, the information to be transmitted is converted to digital form and is d through a Gaussian filter. The individual bits of the digitized information are thereby modified i ndance upon one or more preceding bits. The so modified signals may then be encoded (or m e been encoded before passage through the Gaussian filter) and used to frequency modulate a carrie The modulated carrier wave having, as its modulation, the digitized, modified encoded information, is itted.

As stated above, the information is tra d in packets and each packet comprises a header including a predetermined bit sequence and a ss.

A base station transmits the modulated , to mobile receivers (transceivers) such as mobile telephones. Where the transmission is effe a city environment, reflections from buildings, for example, causes multipath interference so tha ceived signal may include echoes (caused by different path lengths of reflected signals) along with th ed signal. The different path lengths may distort each wanted signal by the preceeding signals o eriod 4T equivalent to the transmission time of for example, four data bits of the wanted signal (w is the bit interval).

The invention is directed to extracting t nted signal from the distorted signal caused by the multipath inteference.

Referring now to Figure 1, a distorted i d signal is passed from the aerial to baseband frequency converter 10.

The converter 10 outputs I and Q basel storted GMSK signals.

In each packet, the first part of the d received signal corresponds to the predetermined bit sequence. The baseband GMSK signals oise are sampled at bit frequency and converted from analogue to digital values in an A to D c r 12. The initial part of the GMSK signal sequence, the predetermined bit sequence, is fed to a ch npulse response estimator 14.

The distortion of this known predeterm it sequence enables a "channel impulse response" to be estimated. The channel impulse response neasure of the distortion, caused by echoes, which has affected the transmitted information. The estimate may be applied to each of a series of stored signals, from a store 18, in a convolutor 16 e most appropriate stored signal sequences, selected in a selector 20, are fed to a metric generator vhich, on a bit-by-bit basis, the baseband GMSK signal is also fed. The metrics so generated are the Viterbi processor 24 which applies known Viterbi algorithms (as indicated in the trellis diag f Figure 3) to produce the most probable sequence, as detected data, at its output and, in depend on the probable sequence selected, an output of the "last bit" back to the selector 20.

A path store is provided in which prec its are stored. Depending on the value of these preceding bits, selection of corresponding signal sets de for feeding to the metric generator 22 for generation of appropriate metrics in the next data bit inte

The store 18 only holds a reduced set sible data sequences. A full set requires 128 combinations. By using an averaging technique, in a nce with the present invention, this number of stored sequences can be reduced to 32. The av technique to reduce the number of stored sequences is described below.

At the receiver, a set of signals would lly be stored corresponding to all possible combinations of the transmitted signal in the interval -4T < T = bit duration). For the full state equaliser this involves storing 128 patterns, corresponding to a binations of a 7-bit sequence that, when modulated, will produce one of the waveforms. Denoting it response as a_0 ...... a_{-6} (each a_i taking ± 1), then the dependence of the modulated waveform o dual bits in a given time interval is thus:-

	bits
0 →	a_0, a_{-1}, a_{-2}
-T -	a_{-1}, a_{-2}, a_{-3}
-2T	a_{-2}, a_{-3}, a_{-4}
-3T	a_{-3}, a_{-4}, a_{-5}
-4T	a_{-4}, a_{-5}, a_{-6}.

Due to the nature of the filtering appl r to modulation, the bits a_0 and a_{-6} have less effect upon the value of the transmitted waveform tha $_{-5}$ ...... a_{-1}. Rather than completely ignoring their effect, an averaging technique is used to produce a signals that sufficiently approximate the true signal set.

To form the approximate waveform, fc and n = -4, s(t,a) is modified in such a manner:-

a) n = 0

$$s(t_1\underline{a}) \approx g_0(t) \quad (j2\pi h \sum_{i=-5}^{-1} a_i\, q(t-iT))\ \exp\ (j\text{Ø}')$$

where $g_0(t) = \langle \exp(j2\pi h\, a_0\, q(t)) \rangle_{a_0}$

($\langle\rangle_{a_0}$ denotes an averaging over a_0.)

ϕ' is the redefined phase state

$$(\emptyset' \quad \iota \sum_{i=-\infty}^{-6} a_i)$$

b) n = -4

$$s(t_1\underline{a}) = g_{-4}(t) \exp \quad h \sum_{i=-5}^{-4} a_i\, q(t-iT))\, \exp\, (j\emptyset')$$

$g_{-u}(t) = < \exp(j\pi h\, a_{-6}\, \{q(t + 6T) - \frac{1}{2}\})'> a_{-6}$
The function q(t) has the form:-

$$q(t) = \begin{cases} 0 & t \leq 0 \quad \int_{-\infty}^{t} g(u)\, du \\ 1/2 & t > LT \end{cases}$$

where g(u) is the response of a Gaussian low p :er to a data symbol.

It will be seen from the above matheme xplanation that all seven bit data sequences can be closely approximated by only 5 bit data seque

Similarly, the selection of signal sets in lector 20 for feeding to the metric generator can be described mathematically with reference to Fig and 4 of the accompanying drawings.

In constructing the selected signal set for the metric generator 22, for a full state equaliser which would handle delays of up to 4T, all possit nbinations of sequences of length 7 symbols would normally be required at the receiver. To redu complexity at this stage, the averaging technique as described above is performed, so that only se ɜs of length 5 symbols are required in constructing the signal set. If the modulated data sequence is ɜd by s(t,$\underline{a}$), where $\underline{a}$ is the aforementioned 5 bit data sequence, then the signal set (c(t,$\underline{a}$)) is formec gh the complex convolution in the convolutor 16, of the estimated channel impulse response ($\bar{h}$(t)) witl ıodulated data sequence. Also required is the squared modulus of the signal set (|c(t,$\underline{a}$)|²). The metric ɜeds to be generated by the generator 22 is given by

$$\Gamma(\underline{a}) = \mathrm{Re}\{\int_{nT}^{(n+1)T} r(t)c^*(t,\underline{a})\, d \quad 5\int_{nT}^{(n+1)T} |c(t,\underline{a})|^2 dt \qquad (1.1)$$

Where r(t) = I(t) + jQ(t), is the received s

The only implication of the averaging to r the length of the sequence $\underline{a}$ is that detection starts on the previous symbol transmitted rather than th ɜnt symbol; i.e. for a path memory length of N symbols the Viterbi algorithm would give an estimate o ımbol a_{n-N} rather than the symbol a_{n-N+1} of the full state case (a_n denotes the current symbol).

In calculating the signal set, it should be :hat only half of the modulated data sequences need to be stored. Further in convolving the modulate with the channel impulse response estimate, only these sequences need be used. To generate the rer ı half of the signal set it is only necessary to sum terms involving the imaginary part of the sequence s ith differing sign. This is described mathematically as:

Denote sequence with opposite sign as -a he signals for these sequences are generated as:

Re{c(t,$\underline{a}$)} = Re{s(t,$\underline{a}$)}⊗Re{h(t)}-Im{s(t,$\underline{a}$)}⊗| } (1.2)

$\mathrm{Im}\{c(t,\underline{a})\} = \mathrm{Im}\{s(t,\underline{a})\}\otimes\mathrm{Re}\{h(t)\} + \mathrm{Re}\{s(t,\underline{a})$ ... $\text{ı}(t)\}$ (1.3)

Further the multiplication by 0.5 in the ... ıs of the signal set (as in equation 1.1) need not be done if the store modulated data has the followin(

$s(t,\underline{a}) = (1/\sqrt{2})\exp(j\phi(t,\underline{a}))$ (1.6)

The important point here is the multiplic ... ›y $1/\sqrt{2}$.

The sixteen selected signal sets are fe ... the signal selector 20 to the metric calculators 23 of the metric generator 22 together with the sarr ... ›aseband GMSK signals. The generator 22 produces the metrics which are used in the processor 24 ... ted above.

In calculating the metrics, it is only nec ... to use one sample/symbol. Consequently the FIR filtering or correlation process reduces to a single ı ... cation. The effect of the accumulated phase in the metric generation process is to require the I and (... to be correlated with both the real and imaginary parts of the signal set, thus four correlators are us ... generate one metric. However because the accumulated phase takes the values $0,\pi/2,\pi,3\pi/2$, it is or ... essary to perform two of the correlations in correlators 25. Which pair depend upon the phase stat(... anding expression 1.1 for the metric, and denoting the accumulated phase as θ the process descri ... ›ove is readily seen.

$$\Gamma(\underline{a}) = \cos(\theta)\left(\int_{nT}^{(n+1)T}\mathrm{Re}\{c(t \ \ldots \ t)\,dt + \int_{nT}^{(n+1)T}\mathrm{Im}\{c(t,\underline{a})\}Q(t)\,dt\right)$$

$$+\sin(\theta)\left(\int_{nT}^{(n+1)T}\mathrm{Re}\{c(t, \ \ldots \ t)\,dt - \int_{nT}^{(n+1)T}\mathrm{Im}\{c(t,\underline{a})\}I(t)\,dt\right)$$

$$-\,0.5\int_{nT}^{(n+1)T}|c(t,\underline{a})|^2\,dt \qquad (3.1)$$

$$\theta = \mathrm{Mod}_{2\pi}\left(\pi/2\sum_{i=-\infty}^{m-4}a_i\right) \qquad (3.2)$$

As stated hereafter in the description ... processor 24, the selection of which signals to use in the generation of the metrics depends upon ... th store content, the phase states, (values of θ) are also determined from the path store. The metri ... ration process for a given sequence $\underline{b}$ is shown in Figures 2 to 4.

The metrics generated in the generatc ... ›e fed to the processor 24 which determines probability on the basis of state trellis diagrams as showr ... ure 5.

Given the sixteen signals, the number ... :es in the trellis is 64, which includes a set of phase states to account for the accumulated phase in ... ›nsmitted signal. This accumulated phase can take one of four values (when reduced modulo 2π): (... π, $3\pi/2$. The reduced state equaliser described does not incorporate the phase states. Instead, fo ... state in the trellis, the accumulated phase is calculated based on the contents of the path store ... implication of this on the metric generation process was described above. To reduce further the nu ... ›f states, a subset of the sequence $\underline{a}$ (sequence $\underline{b}$) is used in the Viterbi processing. The sequence $\underline{b}$ ... ength four symbols and consequently there are $\overline{8}$ states in the trellis diagram as shown in Figure 5.

With the phase states removed and tł ... aging technique as described above applied to reduce the length of the sequence $\underline{a}$. a 16 state e(... r results. In this case the Viterbi algorithm performs the following task: a selection procedure is us ... :eep the number of sequences involved in the maximisation of the metric constant. This involves takin ... ences that differ only in the symbol a_{m-4} (where $a_m = a_{n-1}$)

and selecting the sequence with the largest m … This is performed over all such combinations, and the
largest of the surviving metrics forms the bas … the decision about the symbol a_{m-N+1}. To reduce the
number of states to 8, the following modificatio … e procedure outlined above is made: instead of taking
sequences that differ only in the symbol a_{m-4}, … quences of length 4 symbols, that differ in the symbol
a_{m-3} are involved in the maximisation of the … In the 16 state equaliser, at each state in the trellis,
there are two possible transitions. For each … on, there is, at the receiver, a signal (c(t,a) used to
generate the metric in the next symbol interval … e 8 state case, there are now four possible transitions,
depending upon the symbol a_{m-3}. To determin … wo signals to use in generating the metric for the next
symbol interval, the content of the path store i … ined, hence a soft decision is made as to the nature of
the symbol a_{m-3}.

The values of the processed metrics are a … d and the largest processed metric is equivalent to the
most probable signal. This is output for furth … essing to provide the data bit stream constituting the
voice and/or data communication.

Because averaging is used to reduce all p … 7-bit values to 5-bit values, and because of the use of
the contents of the path store to control signal … on, a reduced state processor is possible.

Claims

1. An equaliser, for a radio receiver, co … g a converter for producing, from a received signal,
digital samples at baseband, means for provic … estimate of channel distortion in the received signal, a
store in which are stored signal sets, means … plying the distortion estimate to the stored signal sets,
metric generating means for generating metri … elected modulated signal sets with the digital samples
and a processor for processing the generatec … s in accordance with a Viterbi algorithm to determine
the most probable value of the received signal

2. An equaliser as claimed in claim 1 whe … means for producing an estimate of channel distortion
includes means for comparing a known dat … ence, received as a distorted signal, with the known
sequence and for deriving the estimate therefr

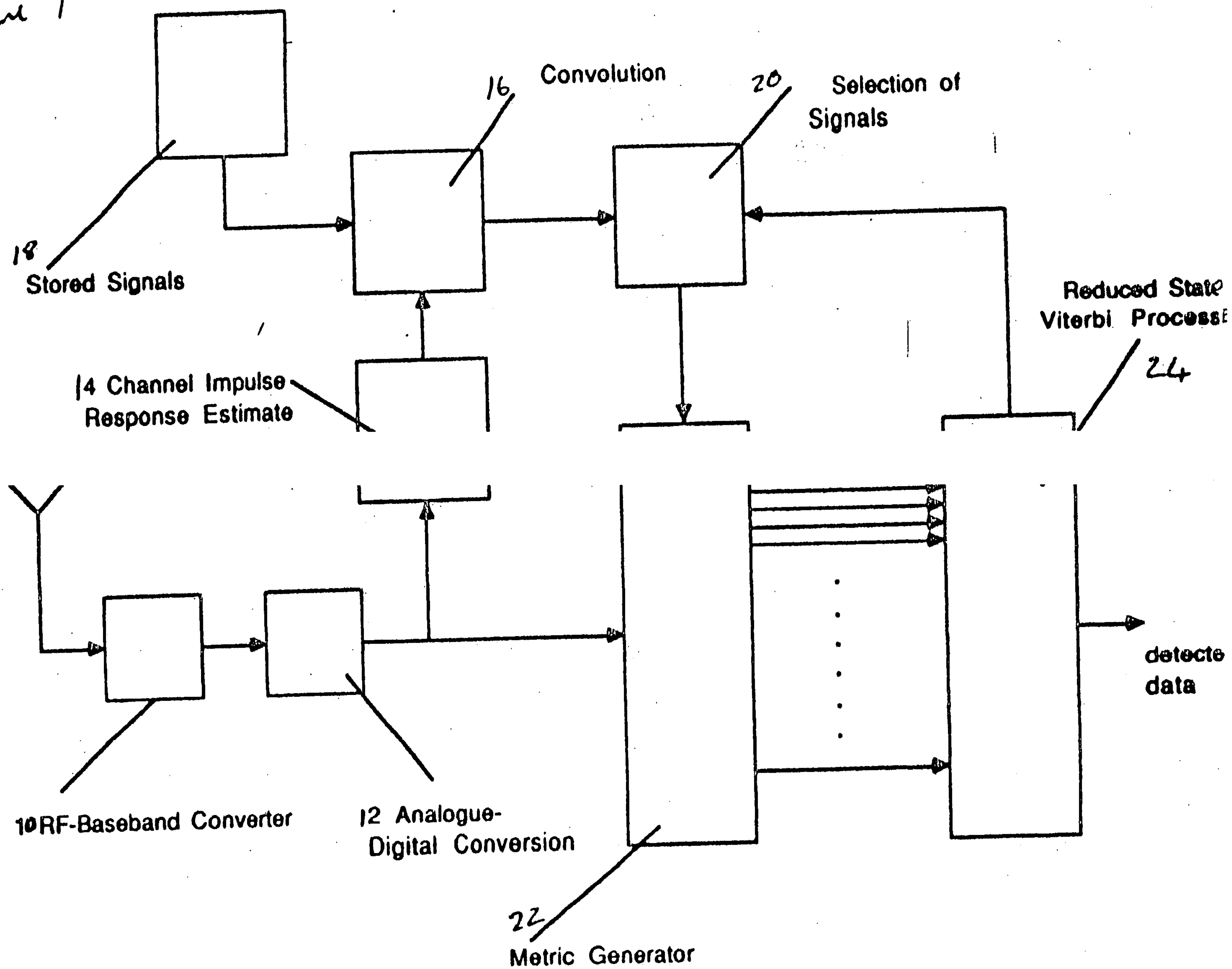
3. An equaliser as claimed in claim 1 … wherein the stored signal sets are 5-bit sequences
representing averaged values of all possible 7 … uences.

4. An equaliser as claimed in claim 3 incl … a state path store and means for selecting a sub-set of
sixteen of stored signal sets which differ on … e symbol a_{m-4}, for use in generating the metrics, in
dependance upon the contents of the state pa … .

5. An equaliser as claimed in any preced … m path store also provides a selection, in dependence
upon the symbol a_{m-3}, to reduce the equaliser … 3-state equaliser.

6. An equaliser, for a radio receiver, su … ally as hereinbefore described with reference to the
accompanying drawings.

Figure 1



18 Stored Signals
16 Convolution
20 Selection of Signals
14 Channel Impulse Response Estimate
Reduced State Viterbi Processor
24
detecte data
10 RF-Baseband Converter
12 Analogue-Digital Conversion
22 Metric Generator

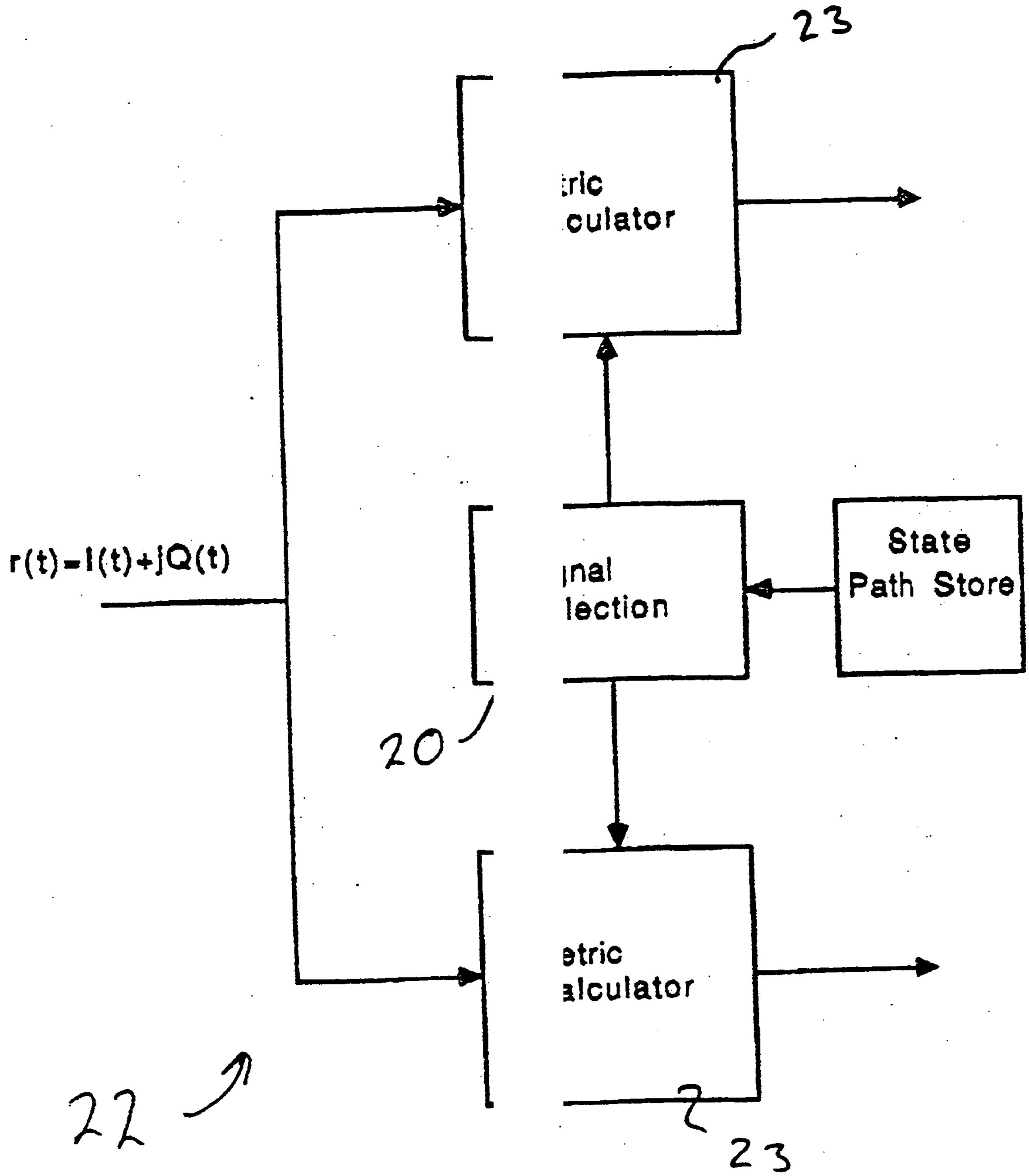


Fig. 2

Metric Generation E ent for Reduced State Equaliser.

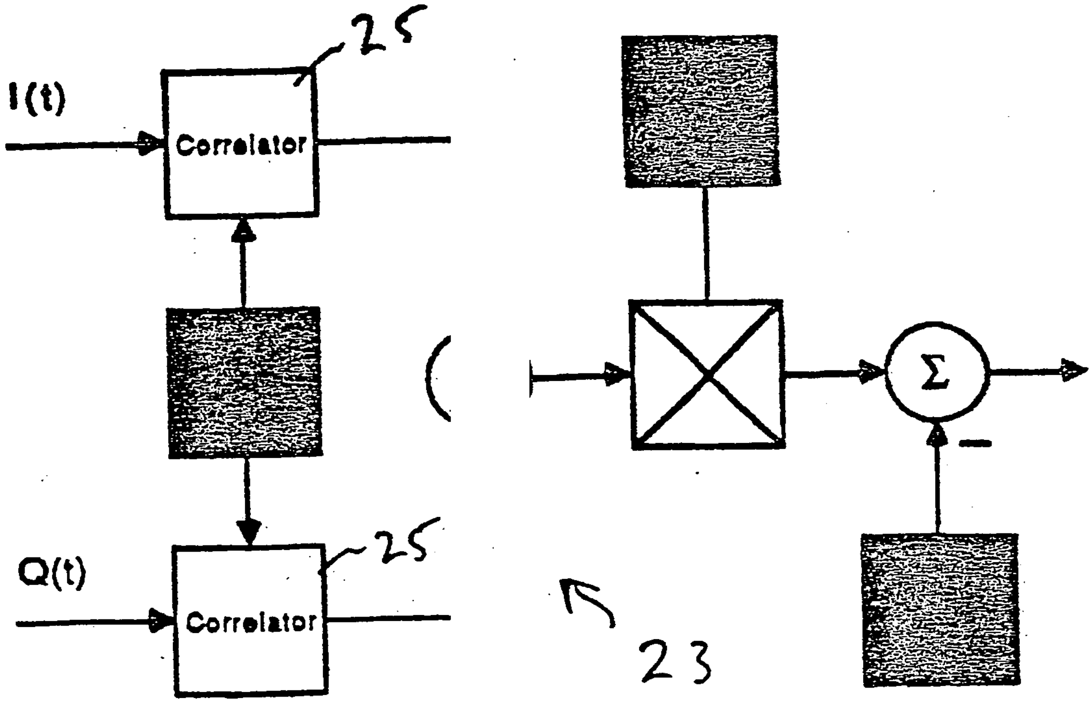


Fig. 3

Metric Calculat

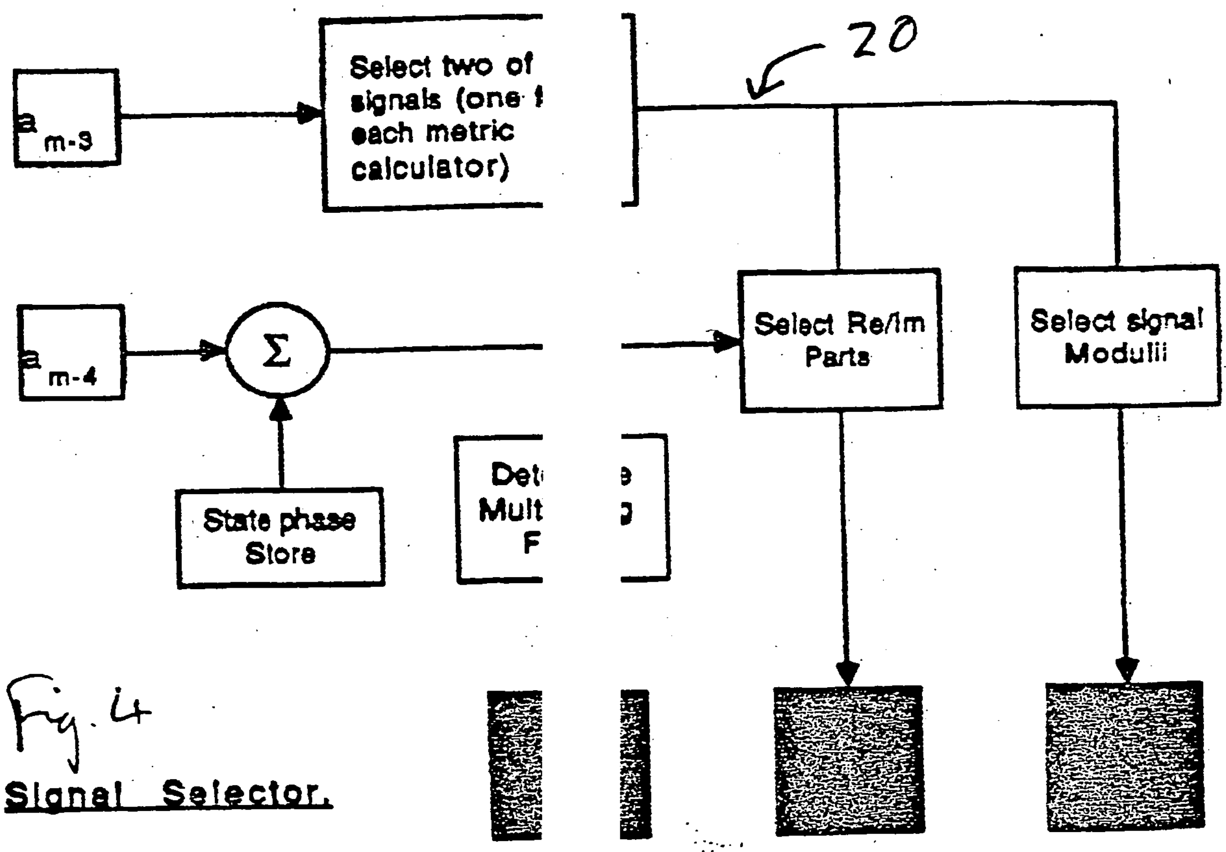
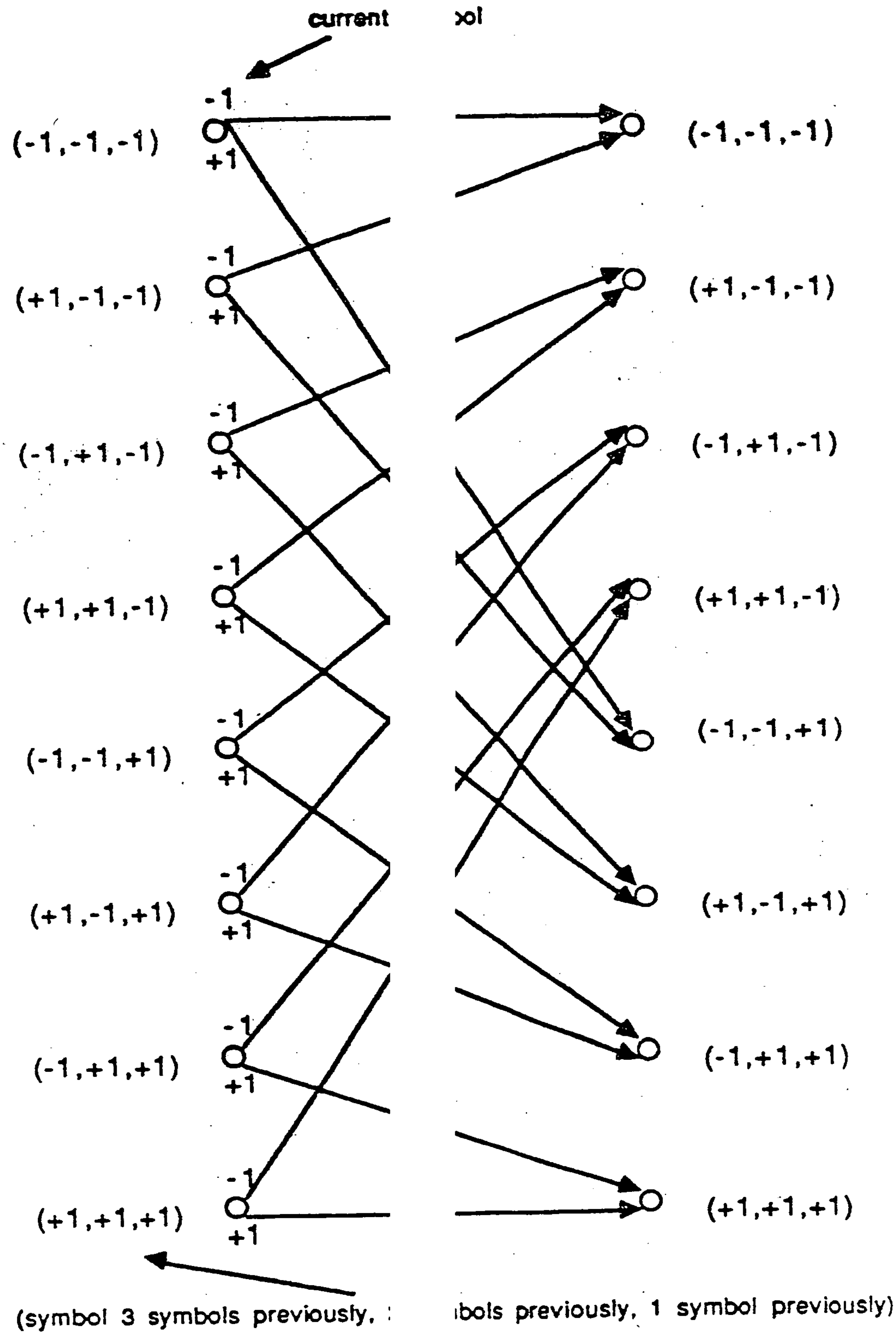


Fig. 4

Signal Selector.



Figur 8 State Trellis Diagram

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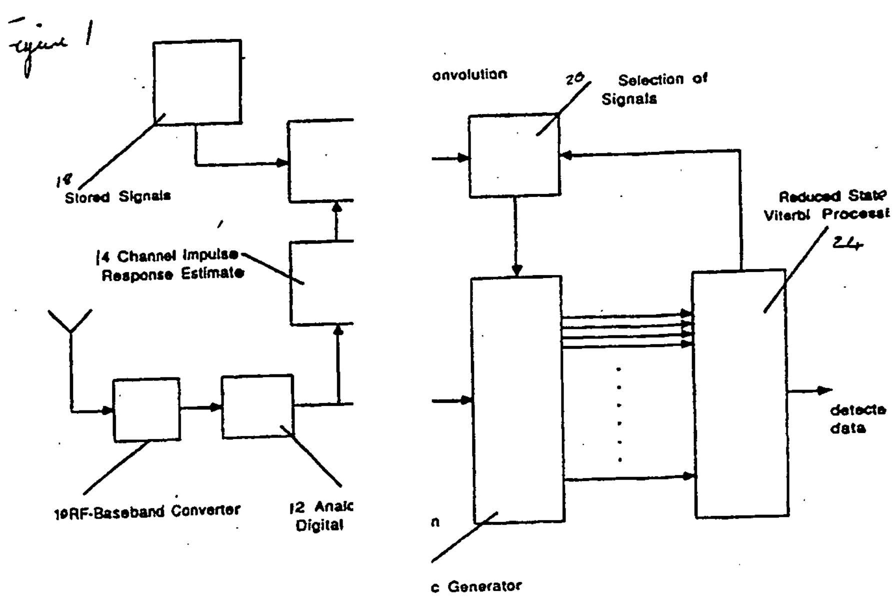

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EP 89 30 1044

DOCUMENTS CONSIDERED T E RELEVANT

Category	Citation of document with indication, whe! irlate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	BELL SYSTEM TECHNICAL JOURNAL, , no. 9, No- vember 1973, pages 1541-1562; D.D. FA ER et al.: "Adaptive channel memory truncation for ıum likeli- hood sequence estimation" * The whole document *	1-5	H 04 L 25/30
A	IEEE TRANSACTIONS ON INFORMATIC ORY, vol. IT-19, no. 1, January 1973, pages 120-12 MAGEE et al.: "Adaptive maximum-likelihood seque imation for digital signaling in the presence of inters nterference" * The whole document *	1-5	
A	DE-A-3 246 525 (LICENTIA) * Abstract; figure 1; claim 1; page 6, lines page 10, lines 11-26 *	1,2	
P,X	WO-A-8 809 591 (SINTEF) * Figure 2, abstract; Page 1, lines 22-34; line 26 - page 4, line 4; page 5, lines 5-17; claims *	1,2	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)
H 04 L H 04 B H 03 M

The present search report has been drawn up for :

Place of search	Date of on of search	Examiner
The Hague	05 ! iber 91	GRIES T.M.

CATEGORY OF CITED DOCUMENTS

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